COMPTON OBSERVATORY OSSE OBSERVATIONS OF SUPERNOVA 1991T

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ABSTRACT

The Oriented Scintillation Spectrometer Experiment on the *Compton Observatory* observed SN 1991T on three occasions in 1991. We find no evidence for ^{56}Co γ-ray line emission from SN 1991T in any of the three observations. Combining these measurements yields a 99% confidence upper limit of 4.1—6.6$\times 10^{-5}$ photons cm^{-2} s^{-1}, depending on how the multiple observations are combined, for the 847 keV line flux in the interval 66 to 79 days post-explosion. The distance to SN 1991T is quite uncertain, but these limits are inconsistent with some theoretical models for distances $\leq$10 Mpc. If we consider Type Ia supernova models at distances at which they would have apparent magnitude B=11.6 at blue maximum, as observed for SN 1991T, then most reasonable models are consistent with our upper limits. However, if we allow for some extinction, as indicated by other observations of SN 1991T, the implied distance for a given model is smaller, the expected γ-ray flux is higher, and many models are no longer consistent with the γ-ray limits. Others are only marginally consistent. These conclusions are significantly strengthened by combining published upper limits from the COMPTEL experiment with those reported here. Together these observations indicate that models of SN 1991T that are relatively optically bright and γ-ray faint, perhaps because of low expansion velocities in part of the ejecta or the presence of an extended envelope, should be investigated further.

Subject headings: gamma rays: observations – nucleosynthesis – supernovae: individual (SN 1991T)

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1. INTRODUCTION

The search for the persistent source of supernova power naturally led to radioactivity, and in particular, to the decay chain ^{56}Ni—^{56}Co—^{56}Fe (Colgate & McKee 1969). This idea was substantiated by observations of the optical light curve of the Type II supernova SN 1987A (Hamuy et al. 1988). Definitive proof awaited the detection of the signature γ-ray lines of ^{56}Co decay (Clayton, Colgate, & Fishman 1969), which was ultimately achieved (Leising & Share 1990, and references therein).

Prior to SN 1987A, it was generally considered that a Type Ia supernovae (SN Ia) would yield the first detection of these γ-rays, because it is thought that the energy of these events is entirely thermonuclear in origin (Woosley & Weaver 1986) and the ejecta masses are small. The Type Ia light curve is supposed to be powered by ^{56}Ni decay initially and later by ^{56}Co. This is the result of the thermonuclear disruption of a white dwarf near the Chandrasekhar mass, a large fraction of which is converted to ^{56}Ni. Calculations indicate that 0.5–1.0 $M_{\odot}$ of ^{56}Ni is ejected, depending on the nature of the nuclear flame propagation, which remains uncertain (Nomoto, Thielemann, & Yokoi 1984; Woosley, Taam, & Weaver 1986;Woosley 1991; Khokhlov 1991; Yamaoka et al. 1992; Khokhlov, Müller, & Höflich 1993). In addition to the large mass of ^{56}Ni, high expansion velocities are expected and observed in Type Ia supernovae. Thus they become thin to γ-rays in a matter of months, when significant ^{56}Co remains.

Besides their intrinsic interest, Type Ia supernovae are important because they can possibly provide a measure of the Hubble constant independent of other distance indicators (Arnett, Branch, & Wheeler 1985). Branch (1992) found an interestingly low value for the Hubble constant using his best estimates for ^{56}Ni mass, rise-time to peak blue magnitude, and efficiency of conversion of decay power to blue luminosity at peak light. If those parameter choices are correct, we must be able to detect the ^{56}Co γ-ray lines from Type Ia supernovae, either with current instruments at distances $\leq$10 Mpc, or with the next generation instruments out to at least the Virgo Cluster center. The best previous search for these lines was for SN 1986G in *Solar Maximum Mission* γ-ray data (Matz & Share 1990). It was somewhat surprising that no emission was detected, but the uncertain distance and unusual characteristics of the supernova offered possible explanations for the nondetection.

Detection of these γ-ray lines remains a major objective of astrophysical nuclear spectroscopy, and seems eventually quite likely when a SN Ia occurs sufficiently nearby. A simple detection would prove that current SN Ia theories are basically on track, while detailed measurements of the light curves and line profiles would help to distinguish among the many possible models. It is the first of these objectives we seek here.

Supernova 1991T was discovered on 1991 April 13 (Waagen & Knight 1991) in NGC 4527, a spiral galaxy on the edge of the Virgo cluster. The explosion probably occurred on about April 10. Its premaximum spectrum, which lacked lines of intermediate mass elements, was unusual for

a Type Ia supernova, but its postmaximum spectra were quite similar to those of normal Type Ia supernovae (Filippenko et al. 1991; Phillips et al. 1992). SN 1991T peaked near V=11.5 on about 1991 April 30 (Phillips et al. 1992), making it the brightest SN Ia since SN 1972E.

The Compton Observatory, launched only a week before the SN 1991T discovery, was thus provided with an opportunity to test the idea of SN Ia as thermonuclear explosions. The observatory's principal axis was pointed toward SN 1991T during the periods 1991 June 15–28 and October 3–17, when both the OSSE and the COMPTEL experiments observed it. OSSE was also able to observe SN 1991T as a "secondary" target during 1991 August 22 – September 5. It is the three observations by the OSSE on which we report here. Preliminary analyses of these data have been reported by Leising et al. (1993). COMPTEL data have also been analyzed and show no excesses from ^{56}Co lines (Lichti et al. 1993a; Lichti et al. 1993b; Lichti et al. 1994). A preliminary reanalysis of the COMPTEL data (Morris et al. 1995) suggests a 2.6σ excess in the sum of two ^{56}Co lines, in conflict with all previous analyses and this work. Investigation of possible systematic errors in that reanalysis is required before its validity can be assessed.

The detectability of γ-ray lines from ^{56}Co decay depends mainly on the mass of ^{56}Ni produced, the ejecta column density, and the distance. The distance to NGC 4527 is uncertain, even relative to the uncertain Virgo cluster center distance (Peletier & Willner 1991). SN 1991T was somewhat brighter at maximum than typical Virgo Cluster Type Ia supernovae (V=12.0, corrected for extinction and distance from the cluster center; Leibundgut & Tammann 1990; Leibundgut 1991). This could be because it had a peak luminosity typical of other SN Ia but is somewhat closer (Phillips et al. 1992), or because it was anomalously luminous and at nearly the same distance as the cluster center (Filippenko et al. 1991). Significant extinction would require even smaller distance or higher luminosity, and how much extinction there actually is becomes an important question, as discussed below. Regardless of these uncertainties, we expect the γ-ray line flux to also be larger than for typical Virgo cluster SN Ia. As pointed out by Arnett (1979) the optical and γ-ray fluxes scale identically with distance and similarly with ^{56}Ni mass, so the ratio of peak γ-ray to peak optical fluxes should be roughly constant for Type Ia supernovae. Therefore we can compare the observed γ-ray to optical flux ratio observed with those predicted by various models.

2. Observations and Data Analysis

The Oriented Scintillation Spectrometer Experiment (OSSE) is one of four experiments on NASA's Compton Gamma Ray Observatory (Johnson et al. 1993). OSSE was designed to undertake γ-ray observations of astrophysical sources in the 0.05 – 10 MeV range. It consists of four identical large-area NaI(Tl) scintillation detector systems with independent, single-axis orientation controls, each with a range of 192 degrees. Each detector has a tungsten slat collimator which defines a $3.8^\circ \times 11.4^\circ$ (FWHM) γ-ray aperture. The total aperture area of the four detectors is 2620 cm^2, with an effective photopeak area at 511 keV of 2000 cm^2.

Table 1: Observation Summary

CGRO Period	Dates (1991)	Days from Explosion	Accumulation Time (10^5 sec)
3	June 15–28	67–79	8.8
8	Aug. 22–Sept. 5	135–148	4.2
11	Oct. 3–17	177–190	6.2

OSSE observations consist of a sequence of two-minute observations of a source field alternated with 2-min. offset-pointed background measurements. The 2-min. duration is selected to be short relative to the typical orbital background variations. When possible, source-free fields 4.5° offset on both sides of the source position along the detector scan plane are used for background observations. In the observations described here, both SN 1991T and the quasi-stellar object 3C 273, which are 1.4° apart, were targets of interest. To achieve reasonable sensitivity to both, the detector axes were pointed between the two targets in source observations. Supernova 1991T was thus located from 0.4 to 0.6° in scan angle from the detector axes for the three observation intervals, and in the third interval it was also 1.1° from the axes in the direction perpendicular to the scan plane. These offsets result in γ-ray line sensitivities slightly worse than nominal OSSE values.

Data screening selects only the highest quality data of both source and background observations. Background estimation is achieved by performing a quadratic fit to three or (when possible) four two-minute background accumulations within six minutes on either side of every two-minute source accumulation. The interpolated background count rate spectrum is subtracted from each source spectrum. The differences are screened for anomalies and then averaged over times appropriate for spectral analysis. Spectra are characterized by constructing a photon spectrum model, convolving the model with the instrument response function, comparing the resultant energy loss spectrum with the observed count rate spectrum, and varying the model parameters until the best agreement is obtained. A detailed description of OSSE performance and spectral data analysis procedures can be found in Johnson et al. (1993).

The three observation intervals are summarized in Table 1. The accumulation times listed are total on-source detector-seconds. Comparable times were spent on background observations. The background-subtracted spectra were averaged over each observation interval. The mean of these three spectra and is displayed in Figure 1. No excess emission at either 847 keV or 1238 keV is apparent in any spectrum. The power-law continuum is attributed to the quasar 3C 273 (Johnson et al. 1995). To quantify the line fluxes we fit each spectrum with a model consisting of a power-law continuum and gaussian lines at 847 keV and 1238 keV. We have six measurements, two lines at three different times, of ^{56}Co in SN 1991T. To extract the most information from our limited statistics we combine these six measurements. In effect we take a weighted mean of them.

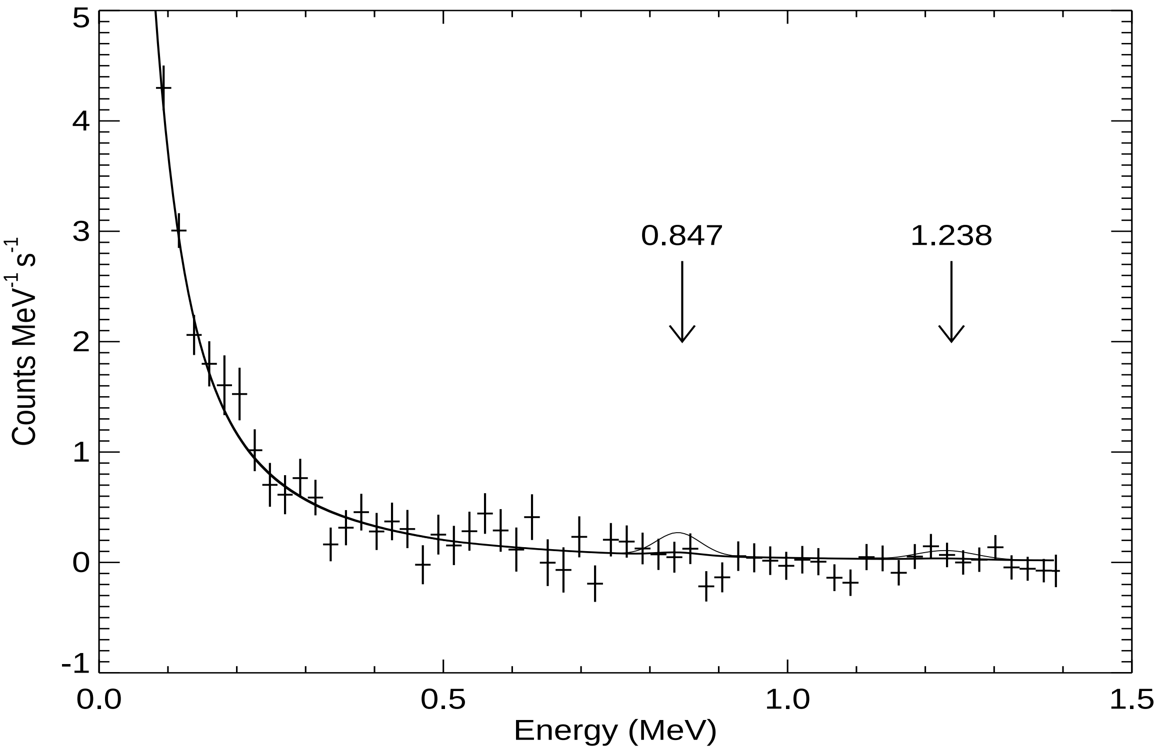

Fig. 1.— The OSSE energy-loss spectrum averaged over all SN 1991T observations. Note that the power-law continuum is attributed to the nearby source 3C 273 (Johnson et al. 1995). The thick solid line is the best-fit power-law plus two gaussian model. The thin solid line shows the expected fluxes in the lines from the model N21 at distance 10 Mpc.

The weights are model dependent because for any reasonable supernova description, we expect the fluxes in the two lines to be different and to vary with time (Burrows & The 1990; Chan & Lingenfelter 1991; Burrows et al. 1991). There are limits to these variations. The decline of the γ-ray line fluxes after maximum can be no steeper than the free decay of the ^{56}Co, in which case the line ratios would be equal to the laboratory value at each epoch. The fastest models decline nearly this steeply after 70 days (Chan & Lingenfelter 1991).

The fastest model we consider is N21 of Höflich, Khokhlov, & Müller (1992, see also Höflich, Khokhlov, & Müller 1994). The procedure we use is to fit all three spectra simultaneously with three independent power-law continua and six gaussian lines with the ratios fixed at the N21 values. The relative line fluxes for the models at the observation times are derived by fitting an analytic model like model 3 of Leising & Share (1990) to the line fluxes which are reported by the authors. The line centroids are fixed at the laboratory energies redshifted by 1700 km s^{-1}, and the intrinsic line widths are fixed at 5% of their energies. The fit therefore has six free continuum parameters and a single free parameter for the lines, which we normalize to the flux in the 847 keV line in the interval 67–79 days after outburst. We quote all results in terms of that flux, but they carry the statistics of all six line measurements. At the opposite extreme of the models we

consider is DET2ENV6 of Höflich et al. (1992, 1994), which becomes thin to γ-rays much more slowly. We also fit the spectra simultaneously with DET2ENV6 relative line fluxes to illustrate the dependence of the measured flux on the relative weights of the multiple line measurements.

For the model N21 the fit to the three average spectra yields a flux $(0.9\pm1.7)\times10^{-5}$ cm^{-2} s^{-1} for the 847 keV line in the first observation. Mapping the increase in the χ^2 statistic versus increasing line flux, with that parameter fixed and all others free, gives a 99% confidence upper limit of 6.6×10^{-5} cm^{-2} s^{-1}. With the relative fluxes of the model DET2ENV6, the best-fit flux is $(0.5\pm1.6)\times10^{-5}$ cm^{-2} s^{-1} for the 847 keV line in the first interval, and the corresponding 99% limit is 4.1×10^{-5} cm^{-2} s^{-1}. This latter limit is lower because for this model more advantage is gained from the later observations; however this is because the model is thicker so lower fluxes are also expected from it.

3. Discussion

Given the distance and the γ-ray escape fraction at 73 days, the flux limits can be converted to limits on the mass of ^{56}Ni produced in the explosion. Because the escape fraction depends on the ^{56}Ni mass through the kinetic energy, and because our combined limits depend slightly on the evolution of the escape fraction, we compare our flux limits directly to some of the current Type Ia models. There are now a number of different classes of models, and many members within the classes. It seems than no model is entirely successful in matching observed light curves or spectra for Type Ia supernovae in general or SN 1991T in particular. Many models fail to reproduce the observed rise times of the light curves and the time evolution and velocities observed in the spectra. The classes of models are defined mainly by the propagation speed of the nuclear burning, which is usually chosen by fiat. Deflagration models have been favored for some time, as pure detonations yield clear contradictions to observations. Hybrid models such as deflagrations which turn into detonations in external layers of the white dwarf ("late detonations") or detonations occurring in pre-expanded dwarfs ("delayed detonations") are also plausible contenders. Detonating white dwarfs inside extended envelopes have also been considered.

In Table 2 we list relevant characteristics of a sample of some Type Ia SN models, separated by class. The list is not intended to be complete, but only to illustrate the variety of models. These models produce a range of different ^{56}Ni masses as shown. The absolute magnitudes in the blue band at maximum are given because we use those to determine the distances at which each model gives B=11.6, as was observed for SN 1991T. These distances then give the expected γ-ray line flux for each model. In Table 2 the γ-ray line escape fraction, f_{esc}, and the line flux at distance 10 Mpc are given for the 847 keV line at 73 days post-explosion.

The model W7 of Nomoto et al. (1984) has been a deflagration standard for several years, but its validity has been questioned (Khokhlov et al. 1993). The difficulty of the radiation transport calculations has led to several different estimates of its peak luminosity and light curve

Table 2: Characteristics of Some Type Ia Supernova Models

Reference	Model	$M(^{56}Ni)$ ($M_\odot$)	M_B^{max} (mag)	f_{esc} 847 keV line, 73 d	$F_{10\,Mpc}$ 847 keV line, 73 d (10^{-5}cm^{-2} s^{-1})	Consistency at 13 Mpc (%)
		deflagration models				
Nomoto et al. 1984[a]	W7	0.58	-19.48	0.56	3.4	5.7
Woosley et al. 1986[b]	CDTG5	0.51	-19.08	0.57	3.0	10.0
Leibundgut & Pinto 1992[b]	CDFA6	0.98	-19.48	0.66	6.7	0.007
		delayed detonation models				
Khokhlov et al. 1993	N21	0.83	-19.71	0.73	6.3	0.03
Khokhlov et al. 1993	N32	0.56	-19.39	0.66	3.8	3.6
Woosley 1991[b]	DD3	0.97	-19.63	0.59	6.0	0.03
Woosley 1991[b]	DD4	0.62	-19.37	0.54	3.5	4.7
		late detonation model				
Yamaoka et al. 1992	W7DT	0.78	⋯	0.62	5.0	0.33
		other models				
Khokhlov et al. 1993[c]	PDD3	0.49	-19.32	0.77	3.9	4.0
Khokhlov et al. 1993[c]	DET2ENV2	0.63	-19.40	0.71	4.7	0.98
Khokhlov et al. 1993[c]	DET2ENV6	0.63	-19.14	0.55	3.6	3.9

[a]Peak blue magnitude from calculation of Khokhlov et al. (1993)

[b]Peak blue magnitude from fit of late-time γ-ray deposition function for model to canonical observed bolometric light curve; we estimate γ-ray escape from quoted deposition at 60 and 100 days.

[c]847 keV line flux derived from total γ-ray luminosity curves of Höflich et al. (1992)

shape (Branch 1992). We quote the value obtained by Khokhlov et al. (1993) for the peak blue magnitude, and the γ-ray escape given by Shigeyama et al. (1993). For the delayed detonation models N21 and N32, the blue light curves are calculated by Khokhlov et al. (1993) and the γ-ray line light curves by Höflich et al. (1992). For the other models of Khokhlov et al. (1993), we derive the line escape and fluxes from the total γ-ray luminosities given by Höflich et al. (1992). We note that the "pulsating" delayed detonation model PDD3 and the envelope model DET2ENV2 (Khokhlov et al. 1993) are favored by Höflich et al. (1994) for fitting the optical light curve. Leibundgut & Pinto (1992) have circumvented the problems of calculating optical light curves near maximum light by developing a canonical post-maximum bolometric light curve from combined observations of several supernovae and fitting that curve to the late-time energy deposition of several models. This fit then yields the required bolometric luminosity five days after maximum, if a given model is to be considered a successful Type Ia model. This luminosity is presumably converted to peak blue magnitude based on observed light curves. We use their calculations of a number of models assuming peak blue magnitude occurs at 18 days after the explosion. We estimate the γ-ray escape using an analytic model fitted to the quoted γ-ray

deposition luminosities given at 60 and 100 days.

As discussed by Lichti et al. (1994) most reasonable distance estimates are in the range 10–13 Mpc. At 10 Mpc the OSSE measurements alone rule out some models listed, while other models are consistent with the measurements at rather low confidences. At 13 Mpc most models are not in serious conflict with the OSSE measurements. Of course the most stringent test of a model is whether it agrees with all measurements. We thus compare the models with all six OSSE line measurements and all four COMPTEL line measurements (Lichti et al. 1994) simultaneously. Because COMPTEL is somewhat more sensitive than OSSE at these energies, we expect to rule out a number of additional models. Lichti et al. (1994) list only a single probability (the flux at 2σ) for each measurement, so we assume that their measurements can be characterized by normal distributions with zero means and widths equal to one-half the quoted limits. This assumption can not be too bad; their equation (1), which is actually a sensitivity calculation, is valid as an upper limit only if the measured count rate N is small. Also, there is no hint of any excesses in their likelihood maps at the position of SN 1991T. We fit all ten line measurements with the relative fluxes of each model in Table 2 and calculate the probability from χ^2 that each is consistent with the measurements for a given distance. The last column of Table 2 gives these probabilities (in per cent) for a distance of 13 Mpc. We see that even at this larger distance even the most consistent models are only marginally so.

Arnett (1979) reasoned that if all the peak optical luminosity and the later peak γ-ray luminosity both result from the same radioactive decay and *if* those luminosities equal the decay power at their respective times, then the ratio of the two peak luminosities would be independent of distance and ^{56}Ni mass. His relation between maximum 847 keV line flux (at roughly 70 days) and peak apparent blue magnitude, as revised by Gehrels, Leventhal, & MacCallum (1987) is

$$\log(F_{847}/10^{-4}cm^{-2}s^{-1}) \;\geq\; 0.4(11.0 \pm 0.9 - B^{max}). \tag{1}$$

The inequality allows for extinction along the line of sight to the supernova. Indeed, this relation partly defined our requirements for observing a Type Ia supernova. Because not all the assumptions inherent in this relation are satisfied (see below), we use a similar relation for those models we consider,

$$\log(F_{obs}/10^{-4}cm^{-2}s^{-1}) \;=\; 0.4(30 + 2.5\log(F_{10\,Mpc}/10^{-4}cm^{-2}s^{-1}) + M_B^{max} - B^{max}). \tag{2}$$

Here F_{obs} and B^{max} are observed, the latter being corrected for extinction, and $F_{10\,Mpc}$ and M_B^{max} are calculated for the model. Both fluxes are for the same line at the same time (the 847 keV line at its maximum, or at 73 days in our analysis.)

We follow Leising et al. (1993) and plot the 847 keV line flux versus the peak blue apparent magnitude for several models (Figure 2). The position along a given model line is simply a function of distance. Note that Ruiz-Lapuente et al. (1993) have made a similar analysis, but have chosen to compare to the brightness in the B band at 73 days. That choice avoids some of the model uncertainties due to the complicated maximum light calculations, but replaces them with the

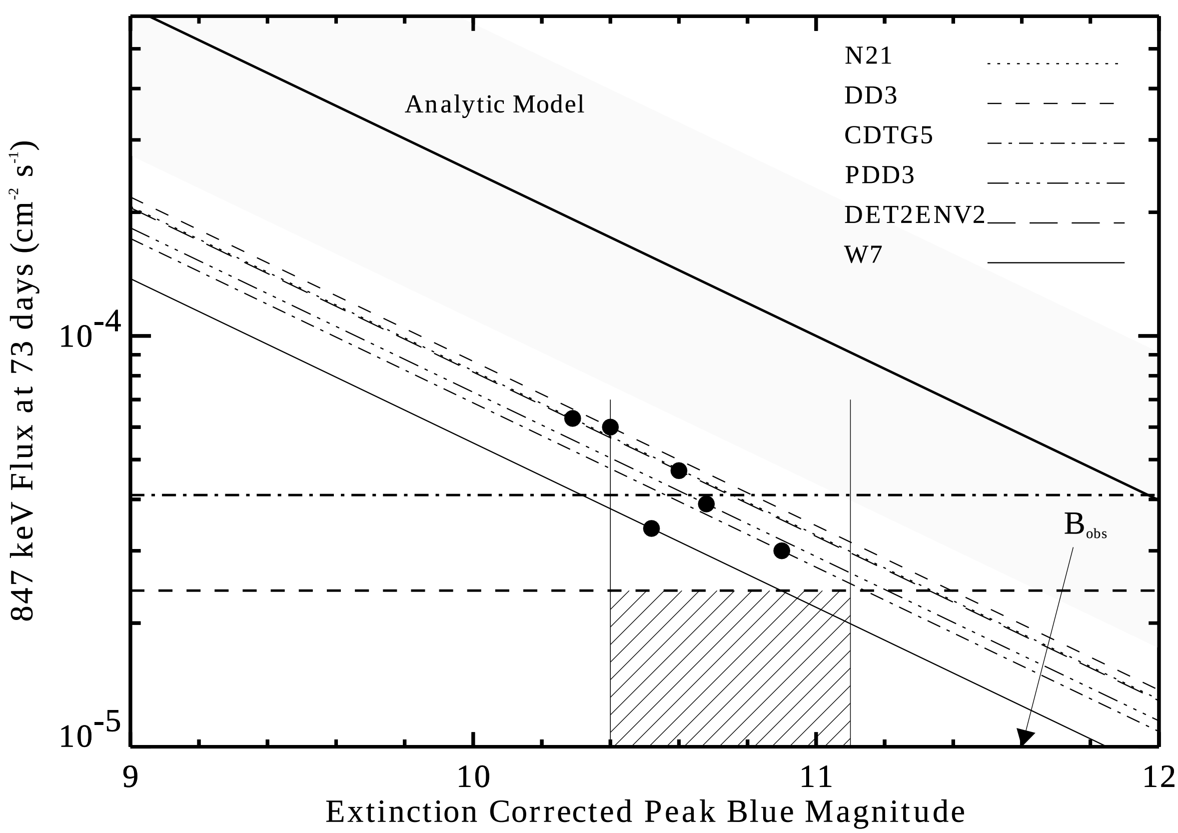

Fig. 2.— The γ-ray line flux at 73 days versus peak B magnitude (corrected for extinction) for a number of numerical models (see Table 2) and for the analytic expression (the shaded region) of Gehrels et al. (1987). For reference the large dots show the location of each model at a distance of 10 Mpc. Also shown for SN 1991T are the observed B at maximum, and the range of corrected B corresponding to $0.5\,mag \leq A_B \leq 1.2\,mag$ (bracketed by the vertical lines). The horizontal lines show the 99% confidence limits for OSSE alone (thick dash-dot line; model DET2ENV2) and for COMPTEL and OSSE combined (thick dashed line; model W7). These limits are somewhat model dependent because the weights used to combine the multiple observations vary from one model to another. The diagonally hatched area is the observationally allowed region for SN 1991T.

uncertainties in the B band calculations at $\geq$50 days (Khokhlov et al. 1993). Their comparison rules out models such as N32 and DF1 with rapid declines in the B band; but those would already be ruled out for SN 1991T if the B band light curve calculations could be taken at face value. Besides testing models, Arnett's relation is especially useful for choosing likely γ-ray targets; of course for that purpose we want to use supernova characteristics at (or before) maximum light.

Figure 2 shows equation (2) for the 847 keV line at 73 days for several models listed in Table 2, along with the general equation (1) (Gehrels et al. 1987). SN 1991T was observed to peak near

B=11.6 (Phillips et al. 1992), and the expected 847 keV flux for each model can be read off the plot at that value of the abscissa. All of those expected fluxes are $\leq 2 \times 10^{-5}$ cm^{-2} s^{-1}. However, those curves apply to the extinction corrected apparent blue magnitude, and there is evidence for significant extinction of SN 1991T. From the equivalent width of the Na I D absorption line Filippenko et al. (1991) find A_V=0.7 mag but apply a correction factor to obtain A_V=0.4 mag. Phillips et al. (1992) imply a similar, but uncertain, value. Using assumptions about the intrinsic color of the supernova at maximum, Ruiz-Lapuente et al. (1992) find $A_V \simeq 1$ mag. Thus it seems likely that the blue extinction is $0.5 \leq A_B \leq 1.2$. The vertical lines in Figure 2 illustrate this range. For the largest extinction value only the lowest curve (model W7) is consistent (barely) with the OSSE 99% limit, shown as the dash–dot horizontal line. For the smallest extinction all are consistent with the OSSE limit, but only W7 is consistent with the combined COMPTEL/OSSE 99% confidence limit, shown as the horizontal dashed line. This line depends slightly on the model; that shown is for model W7. *No model is consistent with COMPTEL and OSSE and the observed peak blue luminosity for $A_B \geq 0.8$ magnitudes.* We caution that very low values for the extinction can not be definitively ruled out, so models such as PDD3 and DET2ENV2, which can fit the optical light curves for low extinction values (Höflich et al. 1994), could be consistent with all observations, including γ-ray data at a few percent confidence, at distance $\sim$13 Mpc.

It is interesting that while the basic idea of Arnett (1979) is confirmed by the numerical models – there is a small spread in γ-ray flux for a given blue magnitude among very different types of models – the actual ratio of the two luminosities is quite different from the simple expression (equation [1]; Gehrels et al. 1987), which is also ruled out even for zero extinction by the γ-ray data. We can identify why the numerical models disagree with that expression. The assumption that the radiated luminosity equals the radioactive power at blue maximum is violated by some of the numerical models (Branch 1992; Khokhlov et al. 1993), and more severely by all extrapolations from late-time deposition using the observed bolometric light curve (Leibundgut & Pinto 1992, ; see their Table 2, Column 8, which is inverted). The γ-ray escape is not near unity at $\simeq$ 70 days in more realistic models (see Table 2). Gehrels et al. (1987) avoided these assumptions, but more recent models are generally thicker than theirs. They used γ-ray deposition fractions of 0.05–0.15 at 70 days, while the models in Table 2 have deposition fractions ranging from 0.15–0.30 at that time. This effect makes their equation (22) brighter by $\geq$ 0.5 magnitudes. The corresponding decrease in their equation (23) is of similar size, thus the models are displaced to the left in Figure 2 by $\geq$ 1 magnitude from the analytic expression. The final relation of Gehrels et al. (1987) also depends on the assumed B band bolometric correction at 70 days and the assumed decline in the B band from peak to 70 days. Both of these can vary quite dramatically among models (Khokhlov et al. 1993), although the two effects tend to cancel each other in those models, so that the difference between peak M_B and M_{Bol} at 70 days is more uniform than the decline rate or late bolometric correction. This situation also argues that we should use the peak B to predict the peak γ-ray flux.

4. Conclusions

We find no evidence for ^{56}Co line emission from SN 1991T, in agreement with other searches (Leising et al. 1993; Lichti et al. 1993a; Lichti et al. 1993b; Lichti et al. 1994). None of the variety of models in the literature is entirely satisfactory at explaining the lack of γ-ray lines and the observed blue maximum of SN 1991T. Perhaps models which expand more slowly still, even though they produce a large mass of ^{56}Ni, better explain the observations of SN 1991T. Model FD2 (Ruiz-Lapuente et al. 1993) is one such possibility, if its apparently low kinetic energy is consistent with its large ^{56}Ni mass. Models of explosions inside extended envelopes appear to be promising, if a physical cause of that circumstance can be identified. It is also possible that current calculations do not accurately represent the luminosity at maximum light, and that the radiated luminosity exceeds the instantaneous radioactive power by a significant factor. Some such way of producing optically brighter but γ-ray fainter supernovae is required to explain SN 1991T. These observations argue that future SN Ia should reach peak B of ≤ 11 magnitudes to be observed with the *Compton Observatory*, although the somewhat unusual nature of SN 1991T should be taken into account. In comparative studies of SN Ia, SN 1991T is almost always unusual, especially in that it seems brighter and slower than the average SN Ia (e.g., Phillips 1993). If this is true, then we would expect that the cause, lower expansion velocities and/or larger eject mass, would also make it γ-ray fainter relative to its peak B brightness.

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